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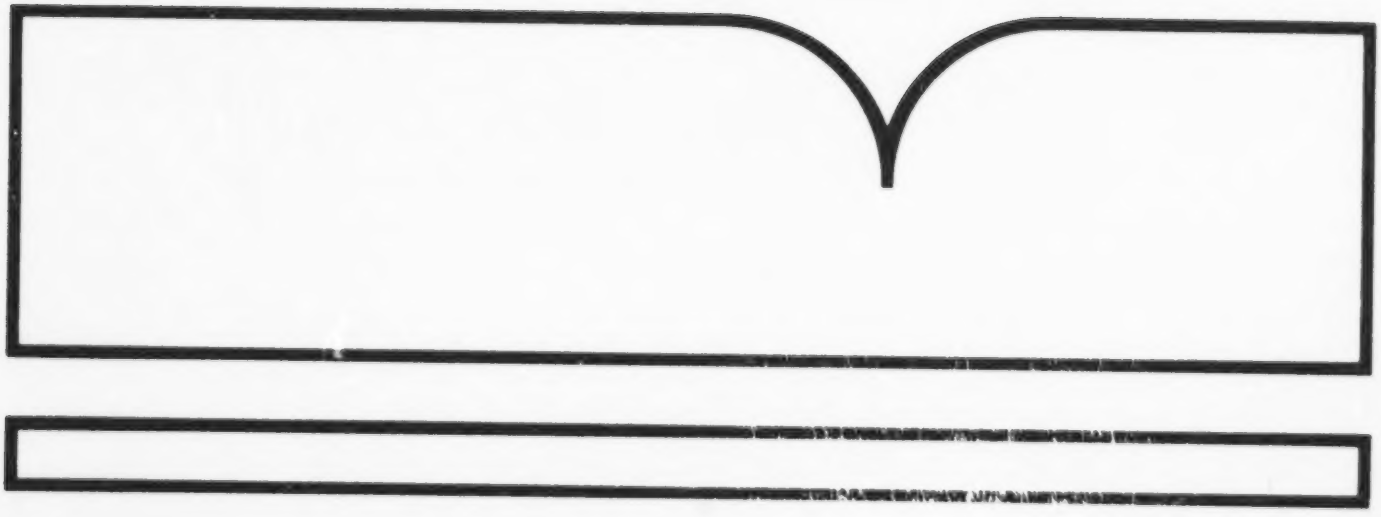
Overview of Indoor Radon Mitigation Alternatives and a Summary of Recent EPA (Environmental Protection Agency) Mitigation Test Results

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Jul 86



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EPA/600/D-86/148
July 1986

AN OVERVIEW OF INDOOR RADON MITIGATION ALTERNATIVES AND A SUMMARY OF RECENT EPA MITIGATION TEST RESULTS

By

D. Bruce Henschel
Alfred B. Craig
Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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16. ABSTRACT The document formed the basis of a discussion of results of EPA tests and documented tests by other research groups on actual houses with elevated indoor radon levels, and is intended to be an overview of mitigation alternatives for radiological health officials, building contractors, and homeowners who are concerned with modifying houses to reduce indoor radon. The discussion is specific to single-family homes (detached houses), as opposed to apartment buildings, other multiple family dwellings, or office and other public use buildings. Introductory information covers indoor radon sources, health effects of radon exposure, radon level monitoring methods, and a discussion on how radon enters and builds up in house air. Covered are nine methods for reducing indoor radon in detached houses: natural and forced-air ventilation, forced-air ventilation with heat recovery, active avoidance of house depressurization, sealing major radon sources, sealing radon entry routes, drain-tile soil ventilation, active ventilation of hollow-block basement walls, and sub-slab ventilation. For each method, information is presented on principles of operation, applicability, how much confidence one can have that the method can achieve radon reduction, and an estimate of installation costs. Where appropriate, drawings depict the details of method installation using terminology familiar to the building trades.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Soils	Pollution Control	13B 08G, 08M
Radon	Stationary Sources	07B
Houses	Indoor Air	13M
Environmental Biology	Health Effects	06F
Measurement		14G
Ventilation		13A

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NOTICE

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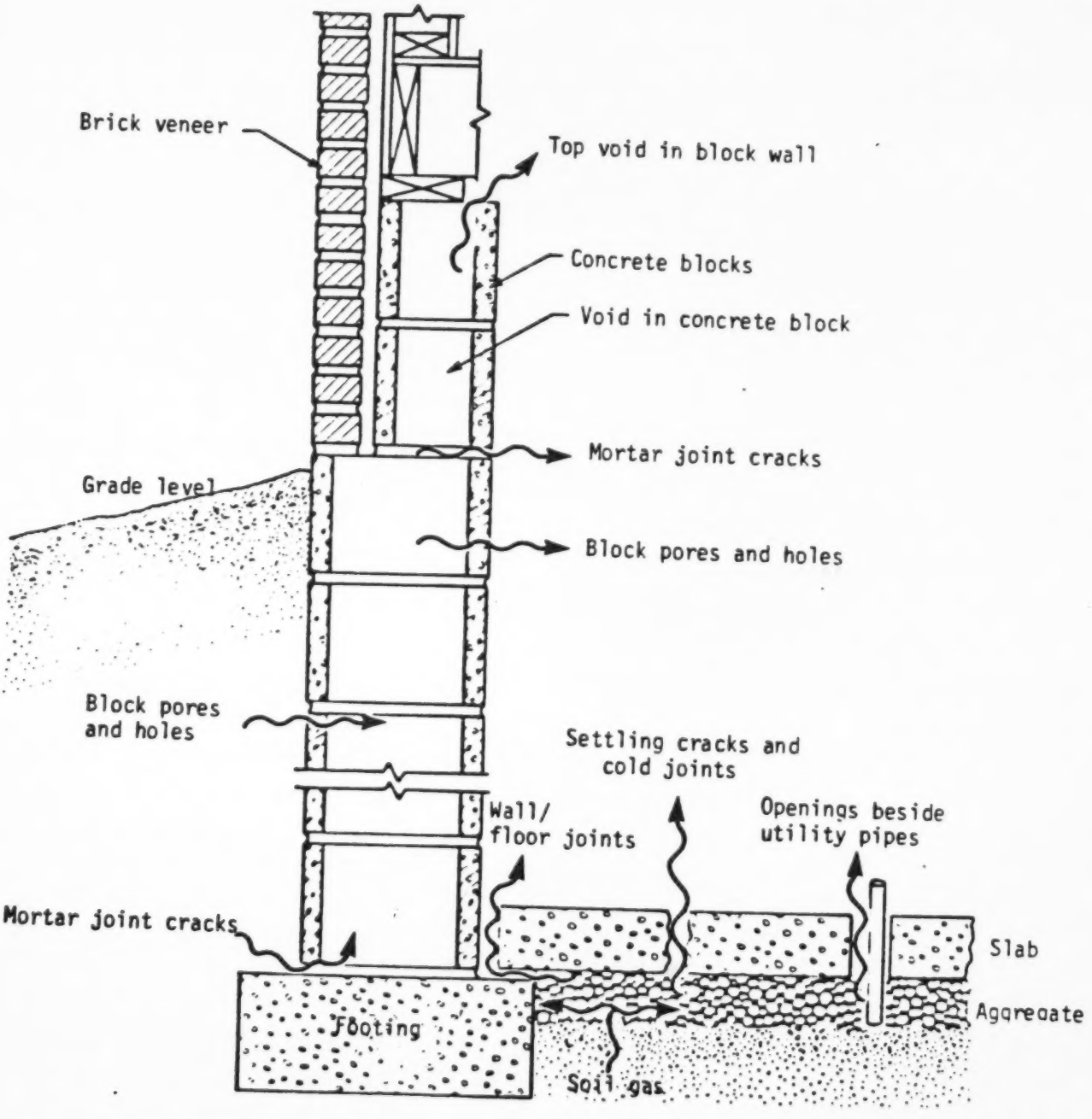
TOPICS

- How does radon get into the house?
- What are the alternatives for reducing radon concentrations in existing houses?
- What radon-resistant features might be incorporated into new construction?
- Some results of EPA's radon mitigation testing



Entry routes for soil gas into a concrete block basement home

CHECKLIST OF POSSIBLE RADON ENTRY ROUTES

A. SOIL GAS ENTRY THROUGH FOUNDATION WALL (BASEMENT HOUSES)

1. UNCLOSED VOIDS IN THE TOP COURSE OF HOLLOW BLOCKS
2. CRACKS IN BLOCKS AND IN MORTAR JOINTS BETWEEN BLOCKS; CRACKS IN POURED CONCRETE WALLS
3. OPENINGS IN WALLS AROUND UTILITY PENETRATIONS (WATER, SEWER, FUEL OIL, ETC.)
4. OTHER HOLES IN WALLS (E.G., DEFECTS IN BLOCKS)
5. PORES IN HOLLOW BLOCKS (CINDER BLOCK GENERALLY MORE POROUS THAN CONCRETE BLOCK)
6. JOINT BETWEEN THE WALL OF THE LOWER LEVEL AND THE SLAB OF AN ADJOINING HIGHER LEVEL IN A SPLIT LEVEL HOUSE
7. FIREPLACE STRUCTURES BUILT INTO WALLS

NOTE: FOR HOLLOW BLOCK WALLS, THE ABOVE LIST APPLIES NOT ONLY TO EXTERIOR PERIMETER WALLS, BUT ALSO TO ANY INTERIOR WALLS WHICH PENETRATE THE SLAB AND REST ON FOOTINGS.

B. SOIL GAS ENTRY THROUGH SLABS AND FLOORS

1. SETTLING CRACKS IN SLABS
2. COLD JOINTS IN SLABS
3. JOINT BETWEEN THE SLAB AND THE WALLS (INCLUDING INTERIOR AS WELL AS EXTERIOR WALLS)
4. OPENINGS IN SLAB AROUND ANY UTILITY PENETRATIONS (WATER, SEWER, ETC.)
5. JOINT BETWEEN THE SLAB AND ANY OTHER INDIVIDUAL PENETRATIONS THROUGH THE SLAB
6. ANY HOLLOW OBJECTS PENETRATING THE SLAB AND OPEN TO THE HOUSE

(CONT.)

CHECKLIST OF POSSIBLE RADON ENTRY ROUTES (CONT.)

7. OTHER HOLES IN SLAB EXPOSING EARTH
8. HOLES IN FLOORING OVER CRAWL SPACES
9. UNTRAPPED FLOOR DRAINS WHICH CONNECT TO DRAIN TILES (OR TRAPPED FLOOR DRAINS WITH RODDING EYE MISSING)
10. SUMPS (GENERALLY CONNECTED TO DRAIN TILES BENEATH THE SLAB OR AROUND THE EXTERIOR OF THE FOOTINGS)

C. SOIL GAS ENTRY THROUGH OTHER ROUTES

1. LEAKAGE OF CRAWL SPACE AIR INTO CIRCULATING HOUSE AIR IN CENTRAL HVAC SYSTEM

D. RADON ENTRY WITH WELL WATER

1. ANY WATER USAGE APPLIANCE IN HOUSES HAVING WELLS WITH ELEVATED RADON CONCENTRATIONS IN THE WATER

DRIVING FORCE FOR SOIL GAS ENTRY

- HOUSES NATURALLY TEND TO BE AT A LOWER PRESSURE THAN THE SURROUNDING SOIL, SO RADON-CONTAINING SOIL GAS IS DRAWN INTO THE HOUSE

- FLOW OF SOIL GAS INTO HOUSE IS INCREASED BY ANY ADDITIONAL DEPRESSURIZATION OF THE HOUSE (OR BASEMENT), WHICH CAN BE CAUSED BY:

  - NATURAL THERMAL STACK EFFECT (MOST PRONOUNCED IN COLD WEATHER)

  - THERMAL BYPASSING (FACILITATES THE STACK EFFECT)

  - APPLIANCES WHICH DRAW AIR OUT OF THE BASEMENT OR HOUSE (FIREPLACES, FURNACES, CLOTHES DRIERS, EXHAUST FANS)

  - OPEN WINDOWS ON JUST THE DOWNWIND SIDE OF THE HOUSE

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

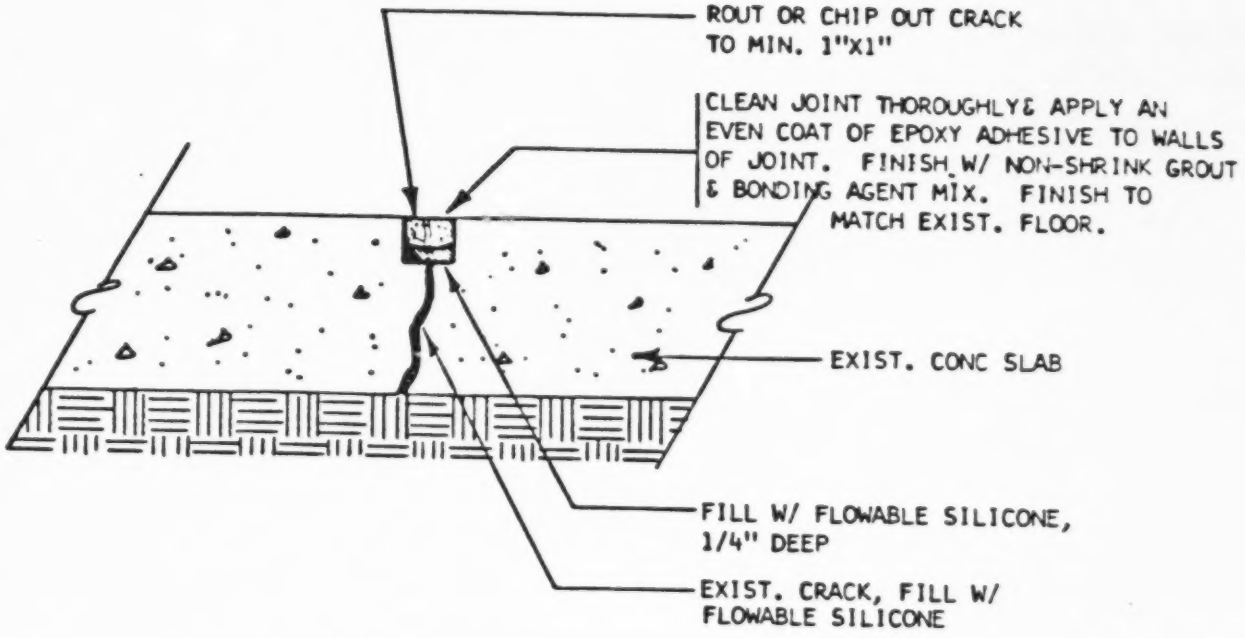
A. HOUSE VENTILATION

- o PRINCIPLE: REMOVE THE RADON AFTER IT HAS ENTERED THE HOUSE (BY DILUTION WITH OUTDOOR AIR)
- o SPECIFIC TECHNIQUES:
  - NATURAL VENTILATION
  - FORCED VENTILATION (USING FAN)
  - HEAT RECOVERY VENTILATOR (HRV) (ALSO KNOWN AS AIR-TO-AIR HEAT EXCHANGER)
- o EFFECTIVENESS DEPENDS UPON INCREASE IN VENTILATION RATE ACHIEVED; REDUCTIONS UP TO 90% HAVE BEEN REPORTED.
- o ADVANTAGES
  - NATURAL, FORCED VENTILATION EASY TO IMPLEMENT, NO (OR LIMITED) INSTALLATION COST
  - "CONVENTIONAL" TECHNOLOGY
  - AT LEAST MODERATE REDUCTIONS REASONABLY ENSURED
- o DISADVANTAGES
  - NATURAL, FORCED VENTILATION MIGHT NOT BE PRACTICALLY APPLICABLE (AND WOULD CAUSE SIGNIFICANT ENERGY PENALTIES) DURING SOME MONTHS IN COLD AND HOT CLIMATES
  - SOME ENEGY PENALTY, EVEN WITH A HRV
  - MECHANISMS BY WHICH HRV'S ACHIEVE REDUCTIONS NOT YET FULLY UNDERSTOOD (MIGHT BE MORE THAN SIMPLE DILUTION); NOT CLEAR THAT VERY HIGH REDUCTIONS CAN ALWAYS BE ENSURED.
- o PRACTICAL CONSIDERATIONS
  - ENSURANCE OF HIGH LEVELS OF REDUCTION WOULD REQUIRE A HRV (FIXED, HIGH INCREASE IN VENTILATION RATE); PRACTICAL ABILITY TO OPERATE YEAR-ROUND WOULD ALSO REQUIRE A HRV
  - MUST ENSURE THAT HRV'S REMAIN BALANCED OVER TIME (FRESH AIR INTAKE/HOUSE AIR EXHAUST)

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

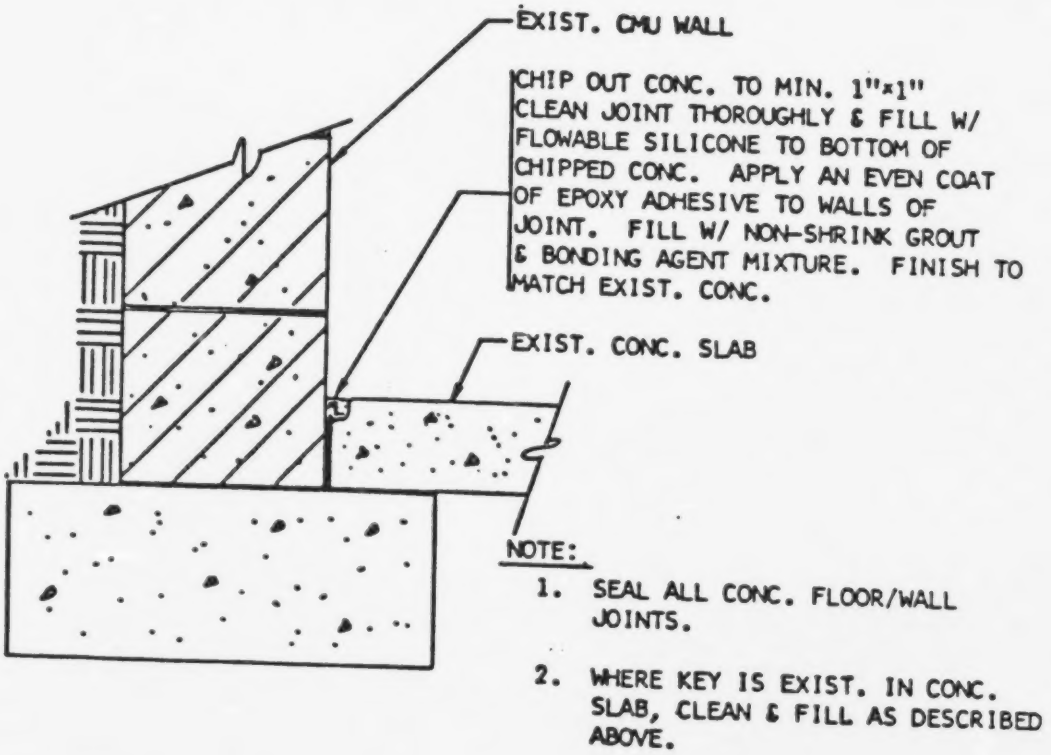
B. SEALING OF SOIL GAS ENTRY ROUTES

- o PRINCIPLE: PREVENT SOIL GAS FROM GETTING INTO HOUSE
- o SPECIFIC TECHNIQUE: PERMANENTLY SEAL ALL OPENINGS BETWEEN THE SLAB (OR FLOOR) AND THE SOIL, AND BETWEEN THE FOUNDATION WALL AND THE SOIL (E.G., USING SEALANTS, COATINGS, MEMBRANES). COVER SUMPS. REMOVABLE PLUG IN UNTRAPPED FLOOR DRAINS.
- o EFFECTIVENESS DEPENDS UPON COMPLETENESS OF SEALING JOB, IMPORTANCE OF THE ENTRY ROUTES SEALED; REDUCTIONS UP TO 90% HAVE BEEN REPORTED.
- o ADVANTAGES
  - TOTALLY PASSIVE, IDEALLY NO OPERATING COST
  - POTENTIALLY THE MOST AESTHETIC APPROACH
- o DISADVANTAGES
  - ENTRY ROUTES TYPICALLY NUMEROUS AND INACCESSIBLE; IT WOULD BE TECHNICALLY VERY DIFFICULT, AND VERY EXPENSIVE, TO COMPLETELY SEAL AN EXISTING HOUSE
  - CRACKS IN THE SEAL CAN RECUR AS HOUSE SHIFTS OVER THE YEARS
- o PRACTICAL CONSIDERATIONS
  - MAJOR, REASONABLY ACCESSIBLE OPENINGS SHOULD ALWAYS BE SEALED; SOME HIGHLY SITE-SPECIFIC REDUCTION WILL LIKELY BE ACHIEVED
  - SEALING WILL OFTEN BE A NECESSARY PART OF OTHER MITIGATION APPROACHES
  - SEALING OF MAJOR OPENINGS MIGHT SOMETIMES BE SUFFICIENT, BY ITSELF, TO REDUCE SLIGHTLY ELEVATED-LEVEL HOUSES DOWN TO "SAFE" LEVELS; SEALING WILL PROBABLY RARELY, IF EVER, BE A COST-EFFECTIVE MEASURE BY ITSELF FOR REDUCING HIGH-LEVEL HOMES DOWN TO "SAFE" LEVELS.


ROUT OR CHIP OUT CRACK
TO MIN. 1"X1"
CLEAN JOINT THOROUGHLY& APPLY AN
EVEN COAT OF EPOXY ADHESIVE TO WALLS
OF JOINT. FINISH W/ NON-SHRINK GROUT
& BONDING AGENT MIX. FINISH TO
MATCH EXIST. FLOOR.
EXIST. CONC SLAB
FILL W/ FLOWABLE SILICONE,
1/4" DEEP
EXIST. CRACK, FILL W/
FLOWABLE SILICONE

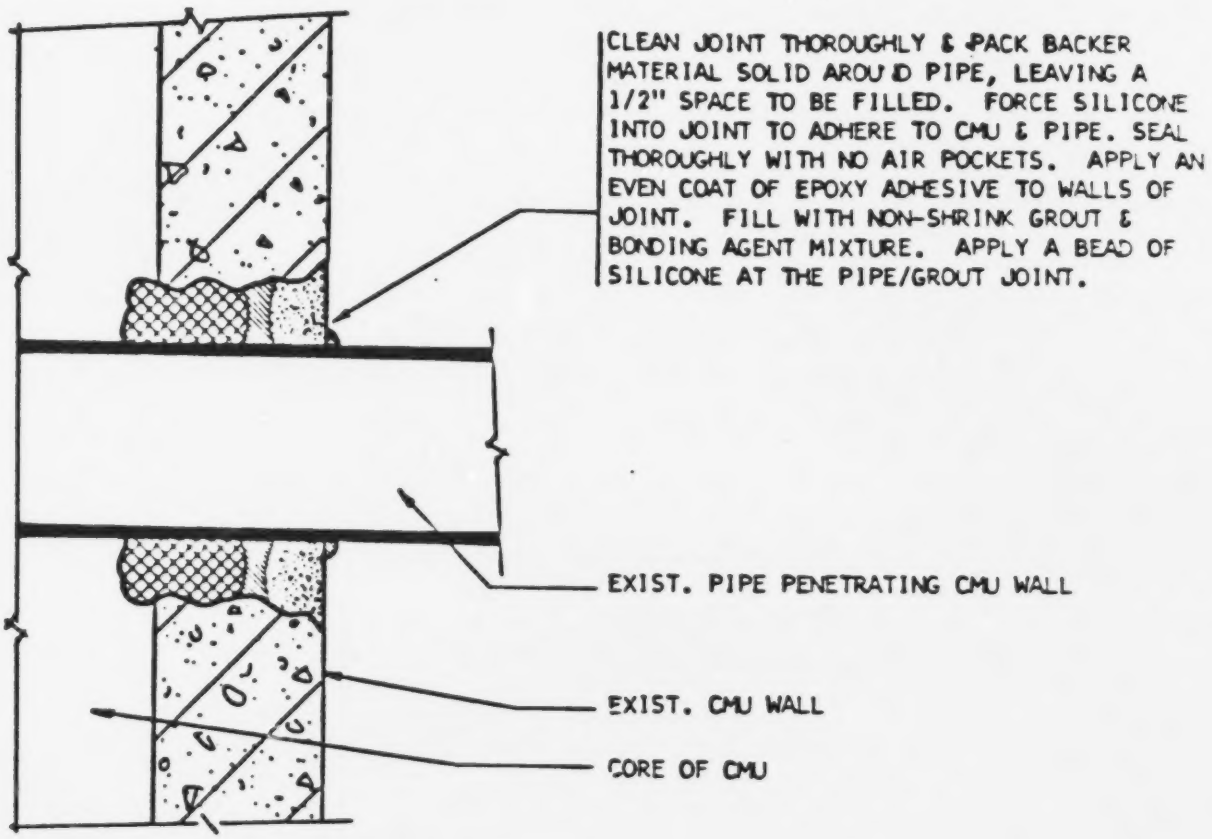
SEALING OF CRACKS IN SLAB

From "General Remedial Action Details for Radon Gas Mitigation"
Pennsylvania Department of Environmental Resources (May 1985)


EXIST. CMU WALL
CHIP OUT CONC. TO MIN. 1"x1" CLEAN JOINT THOROUGHLY & FILL W/ FLOWABLE SILICONE TO BOTTOM OF CHIPPED CONC. APPLY AN EVEN COAT OF EPOXY ADHESIVE TO WALLS OF JOINT. FILL W/ NON-SHRINK GROUT & BONDING AGENT MIXTURE. FINISH TO MATCH EXIST. CONC.
EXIST. CONC. SLAB
NOTE:
1. SEAL ALL CONC. FLOOR/WALL JOINTS.
2. WHERE KEY IS EXIST. IN CONC. SLAB, CLEAN & FILL AS DESCRIBED ABOVE.

SEALING OF WALL/FLOOR JOINT

From "General Remedial Action Details for Radon Gas Mitigation"
Pennsylvania Department of Environmental Resources (May 1985)


CLEAN JOINT THOROUGHLY & PACK BACKER MATERIAL SOLID AROUND PIPE, LEAVING A 1/2" SPACE TO BE FILLED. FORCE SILICONE INTO JOINT TO ADHERE TO CMU & PIPE. SEAL THOROUGHLY WITH NO AIR POCKETS. APPLY AN EVEN COAT OF EPOXY ADHESIVE TO WALLS OF JOINT. FILL WITH NON-SHRINK GROUT & BONDING AGENT MIXTURE. APPLY A BEAD OF SILICONE AT THE PIPE/GROUT JOINT.
EXIST. PIPE PENETRATING CMU WALL
EXIST. CMU WALL
CORE OF CMU

SEALING OF UTILITY PENETRATION THROUGH BLOCK WALL

From "General Remedial Action Details for Radon Gas Mitigation"
Pennsylvania Department of Environmental Resources (May 1985)

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

C. ACTIVE SOIL VENTILATION

- o PRINCIPLE: USE FANS TO DRAW OR FORCE SOIL GAS AWAY FROM THE VICINITY OF THE HOUSE BEFORE IT CAN ENTER. CAUSE THE SOIL AND THE HOLLOW BLOCK VOID NETWORK TO BE AT A PRESSURE LOWER THAN THAT IN THE HOUSE, SO THAT ANY GAS MOVEMENT IS FROM THE HOUSE OUTWARD INTO THE SOIL.
- o SPECIFIC TECHNIQUES:
  - HOLLOW BLOCK WALL VENTILATION
  - SUB-SLAB VENTILATION
  - WALL VENTILATION PLUS SUB-SLAB VENTILATION
  - DRAIN TILE SUCTION
    - -- TAP INTO LINE TO EXTERNAL SOAKAWAY
    - -- COVER AND VENT INTERNAL SUMP
- o REDUCTIONS WELL ABOVE 90% (TO 99+%) CAN GENERALLY BE ACHIEVED, ALTHOUGH THE INSTALLATION COST FOR ACHIEVING SUCH HIGH REDUCTIONS CAN VARY SIGNIFICANTLY DEPENDING UPON SITE-SPECIFIC FACTORS.
- o ADVANTAGES:
  - POTENTIAL FOR HIGH LEVEL OF REDUCTION IN MOST CASES
  - POTENTIAL FOR MODERATE COST IN MANY CASES
- o DISADVANTAGES:
  - CAN BE DIFFICULT/EXPENSIVE TO ADEQUATELY VENTILATE ALL SOIL GAS ENTRY ROUTES IN SOME CASES
  - IS DEVELOPMENTAL (NOT "CONVENTIONAL")
  - SOME ACTIVE SOIL VENTILATION TECHNIQUES CAN BE DIFFICULT/EXPENSIVE TO INSTALL IN FINISHED BASEMENTS
  - SOME CONTINUING OPERATING AND MAINTENANCE COSTS
- o PRACTICAL CONSIDERATIONS
  - WILL LIKELY ALWAYS HAVE TO BE CONSIDERED FOR HIGH-LEVEL HOUSES

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

D. PASSIVE SOIL VENTILATION

- o PRINCIPLE: DRAW SOIL GAS AWAY FROM THE VICINITY OF THE HOUSE BEFORE IT CAN ENTER, WITHOUT USING A FAN. SUCTION IS DRAWN ON A SUB-SLAB PIPING NETWORK BY THE THERMAL STACK EFFECT IN A RISER WHICH PENETRATES THROUGH THE ROOF, AND BY REDUCED PRESSURES AT THE ROOFLINE.

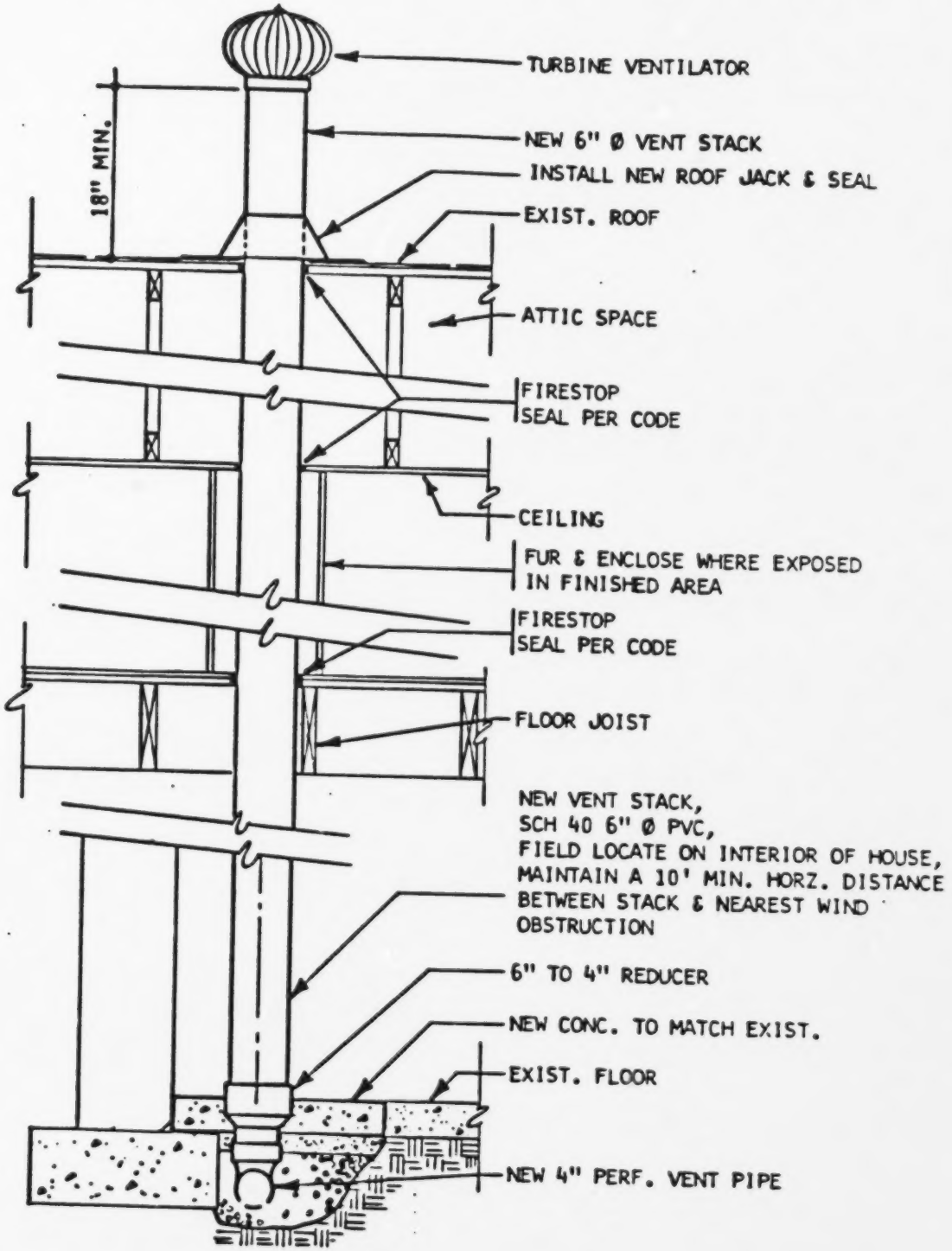
- o SPECIFIC TECHNIQUE:
  - SUB-SLAB VENTILATION

- o EFFECTIVENESS WILL BE HIGHLY DEPENDENT UPON THE EXTENT OF THE SUB-SLAB PIPING NETWORK, WEATHER CONDITIONS, AND OTHER FACTORS.

- o ADVANTAGES:
  - TOTALLY PASSIVE, NO OPERATING COST

- o DISADVANTAGE:
  - SUCTION DRAWN BY THIS SYSTEM IS SMALL; THUS, AN EXTENSIVE PERFORATED PIPING NETWORK MUST BE LAID UNDER THE SLAB TO ACHIEVE ADEQUATE TREATMENT. CAN BE EXPENSIVE TO RETROFIT SUCH A PIPING NETWORK INTO AN EXISTING HOUSE.

- o PRACTICAL CONSIDERATIONS:
  - WOULD BE MOST APPLICABLE WHERE A SUB-SLAB PIPING NETWORK ALREADY EXISTS, OR WHERE THE EXISTING SLAB MUST BE TORN OUT FOR OTHER REASONS.



PASSIVE SUB-SLAB VENTILATION SYSTEM

From "General Remedial Action Details for Radon Gas Mitigation"
Pennsylvania Department of Environmental Resources (May 1985)

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

E. HOUSE PRESSURIZATION

- o PRINCIPLE: KEEP THE HOUSE AT A PRESSURE HIGHER THAN THE SURROUNDING SOIL, SO THAT GAS MOVEMENT IS FROM THE HOUSE OUTWARD INTO THE SOIL.

- o SPECIFIC TECHNIQUE:
  - BLOW AIR INTO THE HOUSE (OR INTO THE BASEMENT) TO INCREASE THE PRESSURE

- o EFFECTIVENESS DEPENDS UPON A NUMBER OF FACTORS (AMOUNT OF AIR SUPPLIED, EXTENT OF SEALING OF PRESSURIZED REGION FROM THE OUTDOORS AND FROM THE REMAINDER OF THE HOUSE)

- o ADVANTAGE:
  - POTENTIAL FOR HIGH LEVEL OF RADON REDUCTION

- o DISADVANTAGES:
  - DIFFICULT TO MAINTAIN ELEVATED PRESSURE UNDER NORMAL CIRCUMSTANCES DUE TO NUMEROUS ROUTES BY WHICH AIR CAN LEAK OUT (E.G., BAROMETRIC DAMPER IN FURNACE FLUE)
  - ENERGY PENALTY IF AIR BLOWN IN FROM OUTDOORS
  - MIGHT MAKE HOUSE FEEL DRAFTY; MIGHT REQUIRE INCONVENIENCES (E.G., CLOSING OFF FIREPLACE)

- o PRACTICAL CONSIDERATIONS:
  - TECHNIQUE IS DEVELOPMENTAL; MIGHT OFFER POTENTIAL ULTIMATELY, BUT PRACTICAL PROBLEMS MUST BE OVERCOME FIRST

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

F. AVOIDANCE OF HOUSE DEPRESSURIZATION

- o PRINCIPLE: TAKE STEPS TO REDUCE HOUSE DEPRESSURIZATION (AND HENCE SOIL GAS INFLUX) CAUSED BY HOUSEHOLD ACTIVITIES AND BY WEATHER.

- o SPECIFIC TECHNIQUES (EXAMPLES):
  - CRACK WINDOW WHEN FIREPLACE IN USE
  - OPEN WINDOWS ON BOTH SIDES OF THE HOUSE
  - PROVIDE OUTDOOR SOURCE OF COMBUSTION AIR FOR FURNACES, OTHER APPLIANCES
  - CLOSE MAJOR OPENINGS BETWEEN FLOORS (REDUCE THERMAL BYPASSING)

- o EFFECTIVENESS HIGHLY SITE SPECIFIC; CAN BE VERY HIGH FOR SHORT PERIODS IN SOME CASES.

- o ADVANTAGES:
  - SOME OF THESE STEPS CAN BE IMPLEMENTED EASILY
  - CAN HAVE MAJOR SHORT-TERM BENEFITS IN SOME CASES

- o DISADVANTAGES:
  - SOME OF THESE STEPS LESS EASY TO IMPLEMENT
  - YEAR-ROUND BENEFITS NOT WELL DOCUMENTED

- o PRACTICAL CONSIDERATIONS
  - WHERE STEPS CAN BE IMPLEMENTED EASILY, THOSE STEPS SHOULD BE TAKEN; SHORT-TERM BENEFITS CAN BE SIGNIFICANT.

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

G. HOUSE AIR CLEANERS

- o PRINCIPLE: REMOVE RADON PROGENY (OR RADON) FROM THE HOUSE AIR
- o SPECIFIC TECHNIQUES:
  - FILTERS, ELECTROSTATIC PRECIPITATORS TO REMOVE PARTICLES (RADON PROGENY) FROM CIRCULATING HOUSE AIR
  - SORPTION UNITS TO REMOVE RADON GAS
- o EFFECTIVENESS AT REDUCING GROSS WORKING LEVEL CAN BE MODERATE TO HIGH; EFFECT ON WORKING LEVEL OF UNATTACHED PROGENY IS AN ISSUE WITH PARTICLE REMOVAL DEVICES
- o ADVANTAGES:
  - CAN GIVE MODERATE AND HIGHER WORKING LEVEL REDUCTIONS
  - GENERALLY "CONVENTIONAL" TECHNOLOGY; DO NOT REQUIRE SIGNIFICANT MODIFICATIONS TO THE HOUSE
- o DISADVANTAGE:
  - PARTICLE REMOVAL DEVICES MIGHT INCREASE THE AMOUNT OF UNATTACHED PROGENY; HEALTH RISKS UNCLEAR
- o PRACTICAL CONSIDERATIONS:
  - EFFECTS OF PARTICLE REMOVAL DEVICES ON UNATTACHED PROGENY, AND THE RESULTING HEALTH EFFECTS, MUST BE CLARIFIED BEFORE THESE DEVICES CAN BE RECOMMENDED.

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

H. WELL WATER TREATMENT DEVICES

- o PRINCIPLE: REMOVE RADON FROM WELL WATER BEFORE IT IS USED IN THE HOUSE AND RADON CAN DE-GAS.

- o SPECIFIC TECHNIQUES:
  - ACTIVATED CHARCOAL TREATMENT OF WATER ENTERING HOUSE
  - OTHER

- o EFFECTIVENESS REPORTEDLY GOOD.

- o PRACTICAL CONSIDERATIONS:
  - LONG-TERM PERFORMANCE IN REDUCING WATER RADON LEVELS, AND PRACTICAL OPERATING REQUIREMENTS, UNDER STUDY.

RADON MITIGATION ALTERNATIVES
(NEW CONSTRUCTION)

- o PLASTIC LINING BETWEEN AGGREGATE AND CONCRETE SLAB
- o SLAB AND FOOTINGS MONOLITHIC POUR
- o UTILITY PENETRATIONS CAREFULLY SEALED
- o POURED CONCRETE PREFERRED OVER HOLLOW BLOCK FOR FOUNDATION WALLS
- o FIREPLACE STRUCTURES, FURNACE FLUES, ETC., BUILT TO PREVENT SOIL GAS ENTRY AND THERMAL BYPASSING
- o FOR HOLLOW BLOCK FOUNDATION WALLS:
  - SOLID CAP BLOCK ON TOP
  - GAS BARRIER ON OUTSIDE FACE OF BLOCK WALL EXTENDING ONTO FOOTING
  - COATING OR LINER ON INSIDE FACE OF BLOCK WALL
  - GAP BETWEEN BLOCK AND BRICK VENEER MORTARED SHUT
- o ADEQUATE VENTS IN CRAWL SPACE

APPROXIMATE COSTS OF RADON MITIGATION (EXISTING HOUSES)

Technique	Approximate % Reduction	Installed Cost ($) By Homeowner	Installed Cost ($) By Contractor	Annual Operating Cost
House ventilation				
1. Natural	Up to 90	0	N/A	4 times heating costs.
2. Forced	Up to 90	Low	to 150	Up to $100 + 4 times heating costs.
3. Heat recovery ventilation	Up to 90+	N/A	400-1,500	Up to $100 + 1.6 times heating costs.
Sealing				
4. Comprehensive sealing	Low to 90	Low to moderate	Low to >10,000	None
Active soil ventilation				
5. Wall ventilation				
- single point	Up to 99+	100-400	2,500+	$150
- baseboard duct	Up to 99+	200-600	5,000+	$150
6. Sub-slab ventilation	Up to 90-99	200-500	2,000+	$150
7. Drain tile suction	Up to 98+	100-300	1,200	$150
Passive soil ventilation				
8. Sub-slab ventilation	*		*	None
House pressurization				
9. House pressurization	*		*	*
Avoid depressurization				
10. Avoid depressurization	*		*	*
Air cleaners				
11. Particle removal devices	*		*	*
12. Gas sorption devices	*		*	*
Well water treatment				
13. Water treatment devices	*		*	*

*Performance/costs highly variable, site-specific (or otherwise unable to estimate at this time).

STEPS IN SELECTING MITIGATION APPROACH

Initial Diagnosis

1. Inspect house for entry routes listed in checklist (pg. 4)

2. Conduct diagnostic tests as necessary to assess importance of various routes. (EPA is developing diagnostic protocols)

   - smoke tracer studies
   - spot radon grab samples
   - other

3. Baseline radon levels

Immediate Action by Homeowner

1. Ventilate to maximum extent practical (ensure good circulation, open windows on both sides of house, fans should blow inward)

2. Close all major accessible openings in walls and floors

Selection of Mitigation Measure

1. For slightly elevated initial radon levels

   - sealing of major entry routes
   - Heat Recovery Ventilators
   - possibly other approaches

2. For highly elevated initial radon levels

   - active soil ventilation (in conjunction with sealing and possibly other approaches)

(Cont.)

STEPS IN SELECTING MITIGATION APPROACH (CONT.)

POST-MITIGATION DIAGNOSIS

1. MONITOR POST-MITIGATION RADON LEVELS OVER SEVERAL DAYS.

2. DIAGNOSTIC TESTING IF SYSTEM HAS NOT REDUCED RADON TO ACCEPTABLE LEVELS.

   - SMOKE TRACER TESTS
   - FLOW RATE, PRESSURE MEASUREMENTS IN ACTIVE SOIL VENT PIPES
   - SPOT RADON GRAB SAMPLES
   - OTHER

3. MONITOR POST-MITIGATION RADON LEVELS FOR SOME EXTENDED PERIOD AFTER SUCCESSFUL TECHNIQUE IS IN PLACE (AT LEAST THROUGH ONE COLD SEASON).

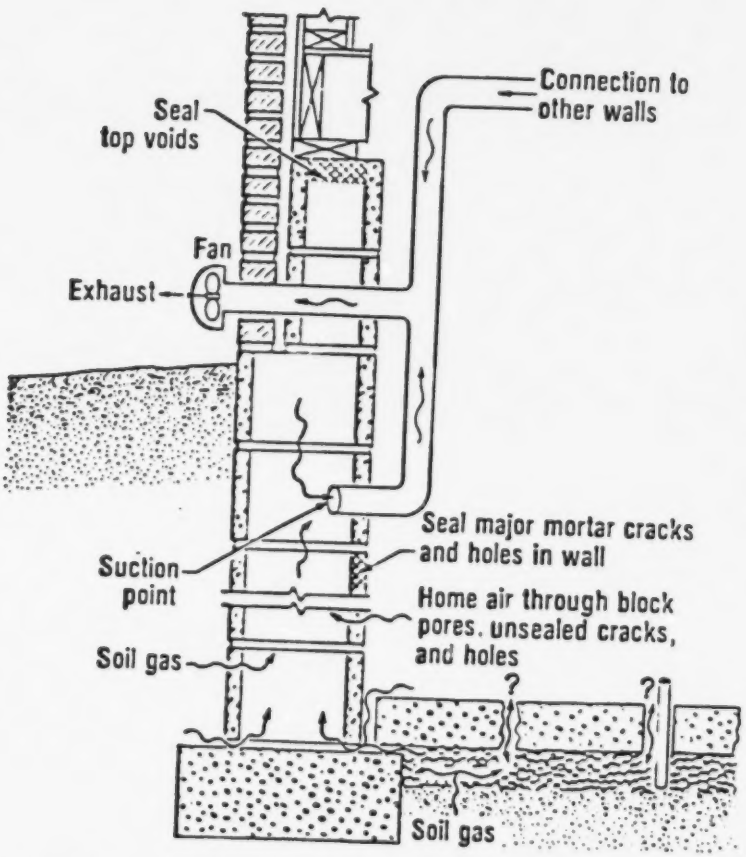
FURTHER INFORMATION ON INDOOR RADON MITIGATION ALTERNATIVES WILL BE PRESENTED IN:

RADON REDUCTION APPROACHES FOR DETACHED HOUSES:
TECHNICAL GUIDANCE

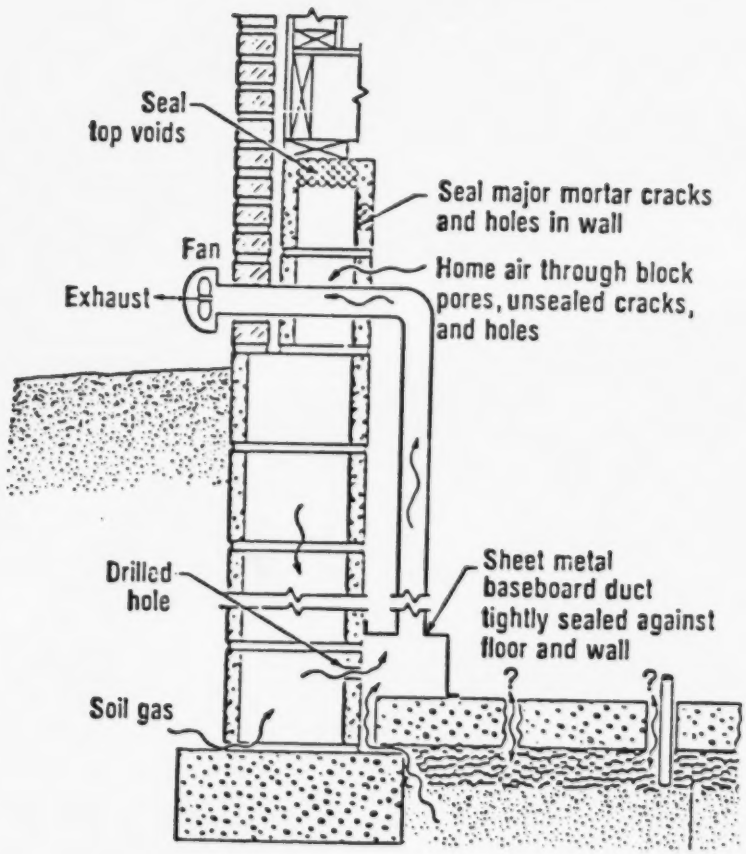
TO BE PUBLISHED BY EPA (~ JUNE 1986)

SOME RECENT RESULTS OF EPA MITIGATION TESTING IN EASTERN PENNSYLVANIA

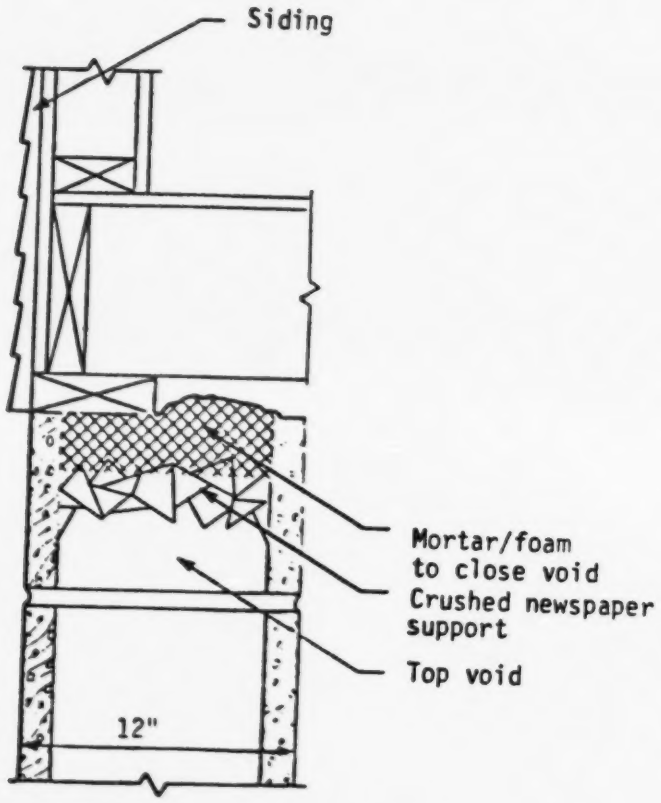
NOTE: THIS TESTING IS THE FIRST PART OF A BROADER EPA-SPONSORED RADON MITIGATION EFFORT



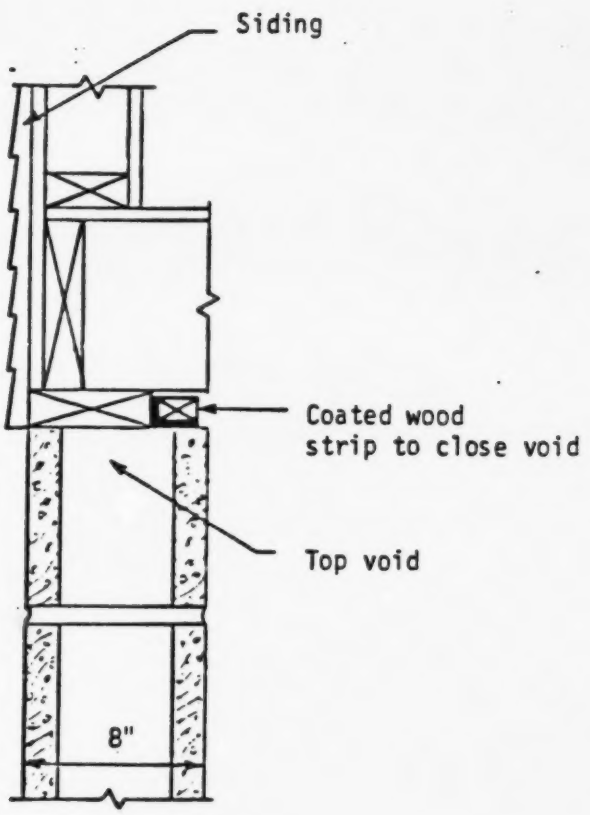
Wall ventilation (individual suction points in each wall)



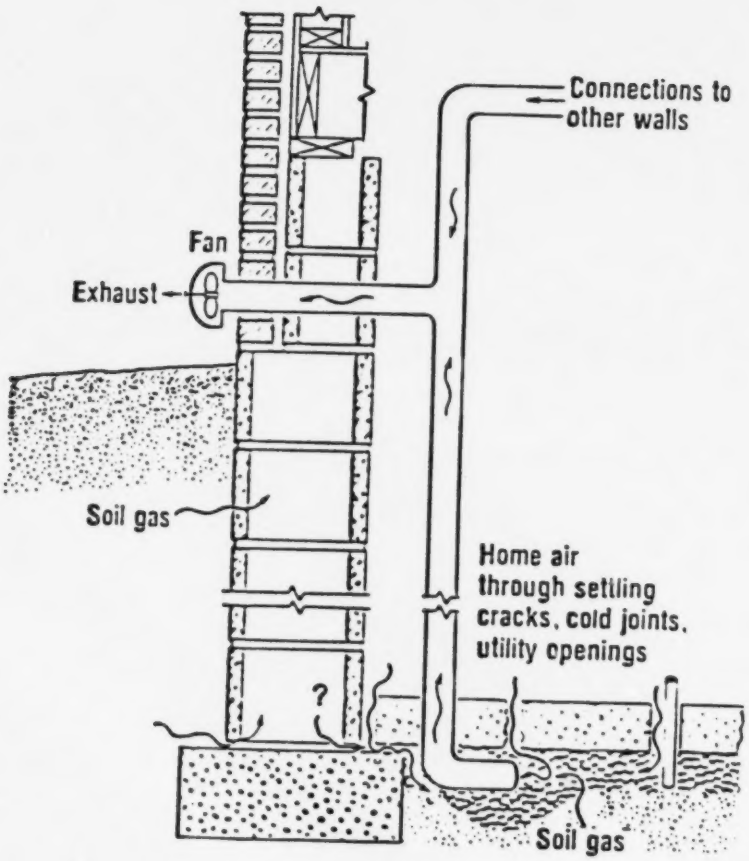
Wall ventilation with baseboard duct



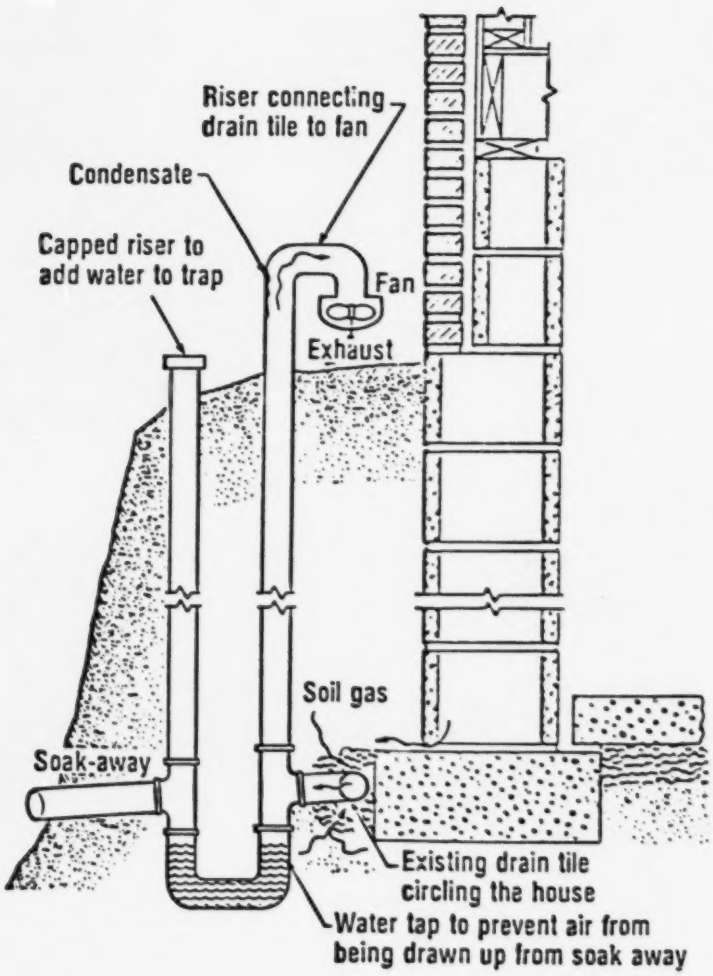
Closing top voids when a fair amount
of the voids is exposed



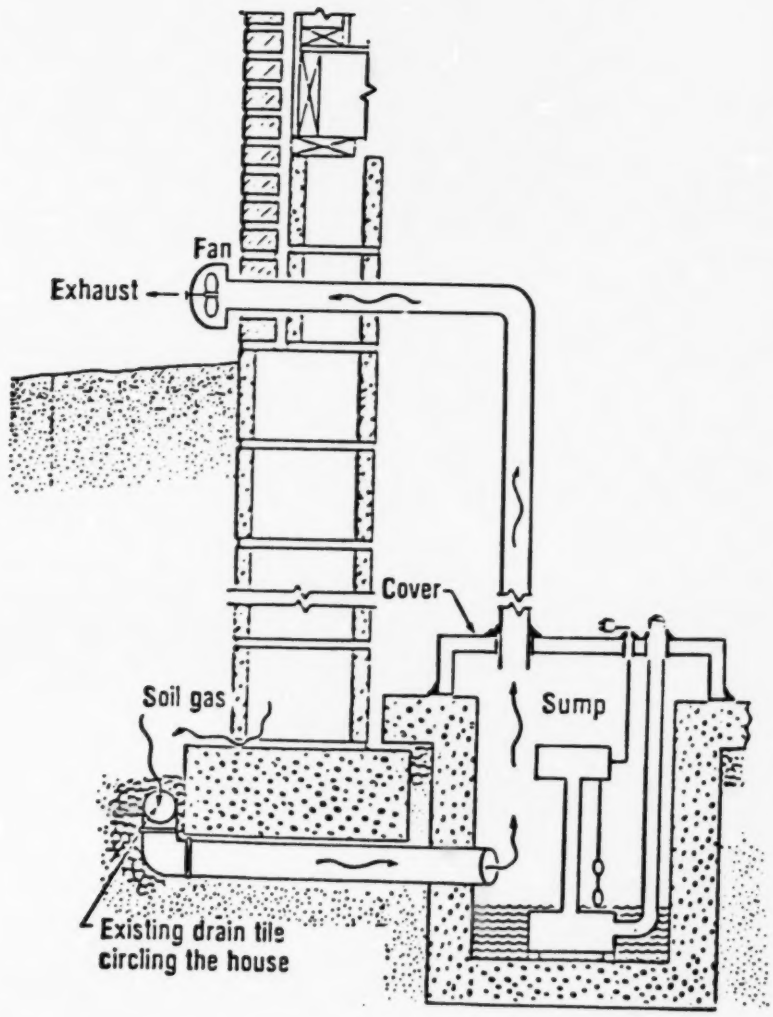
One option for closing top voids when little of the voids is exposed



Sub-slab ventilation


Riser connecting drain tile to fan
Condensate
Capped riser to add water to trap
Fan
Exhaust
Soil gas
Soak-away
Existing drain tile circling the house
Water tap to prevent air from being drawn up from soak away

Drain tile ventilation (with soakaway)



Drain tile ventilation (with sump)

CURRENT RESULTS WITH WALL VENTILATION

House Number	Working Level Before	Working Level After (Winter)	Approx. % Reduction
Individual Suction Points			
3A	4.2-7.4	0.005-0.01	99+
5A	0.30-0.95	0.02-0.07	93
7A	2.0-3.0	0.03-0.33	93
8	0.26-0.80	0.01-0.02	98
14A	0.06-0.40	0.005	98
16A	0.50-1.0	0.009-0.03	97
Baseboard Duct			
1A	0.63-1.0	0.02-0.12	91
2B	0.44-7.0	0.007-0.06	99
9A	1.2-2.4	0.02-0.08	97

CONCLUSIONS ON WALL VENTILATION

- o WHERE MAJOR OPENINGS IN BLOCK WALLS CAN BE EFFECTIVELY CLOSED, AND WHERE THE SLAB IS REASONABLY INTEGRAL (NOT A MAJOR ENTRY ROUTE), WALL SUCTION BY ITSELF CAN REDUCE EVEN WORST-CASE HOUSES TO 0.02 WL AND LESS, AND CAN DO SO AT MODERATE COST (AROUND $2,500). HOUSES 3A, 8, AND 14A REPRESENT SUCH TEXTBOOK CASES.

- o WHERE WALL OPENINGS ARE LESS ACCESSIBLE DUE TO
  - INACCESSIBLE TOP VOIDS
  - EXTERIOR BRICK VENEER
  - FIREPLACE STRUCTURES

  THEN COSTS WILL INCREASE (DUE TO THE SEALING EFFORTS REQUIRED) AND PERFORMANCE MIGHT BE REDUCED.

- o WHERE THE SLAB MIGHT CONTAIN SIGNIFICANT ENTRY ROUTES, THEN A COMBINATION OF WALL VENT PLUS SUB-SLAB VENT MIGHT BE NECESSARY.

- o EFFORTS WILL CONTINUE TO REFINE AND OPTIMIZE THIS TECHNIQUE.

CURRENT RESULTS WITH SUB-SLAB SUCTION

House Number	Working Level Before	Working Level After (Summer)	Approx. % Reduction (Summer)	Working Level After (Winter)	Approx. % Reduction (Winter)
Inadequate Aggregate and/or Major Wall Entry Route					
1	0.63-1.0	0.54-0.94	0	--	
2	0.44-2.5	0.15-0.29	88	1.8-7.4	
3	4.2-7.4	2.5-2.8	58	--	
4	0.2	0.03	85	0.09-0.14	
Adequate Aggregate/Reasonable Wall Entry					
7B	1.4	--		0.01-0.04	98
U-1	3.5	--		0.15	96

CONCLUSIONS ON SUB-SLAB SUCTION

- WHERE THERE IS INADEQUATE AGGREGATE UNDER THE SLAB (AND THE SOIL HAS LOW PERMEABILITY)--OR WHERE A MAJOR WALL-RELATED ENTRY ROUTE EXISTS (E.G., FIREPLACE STRUCTURE WITH INTERNAL OPENINGS)--SUB-SLAB SUCTION APPEARS UNABLE TO PROVIDE HIGH REDUCTIONS SUSTAINED THROUGH THE WINTER MONTHS.

- WHERE REASONABLE AGGREGATE/REASONABLE SOIL PERMEABILITY EXIST--AND WHERE WALL-RELATED ENTRY ROUTES (THOUGH IMPORTANT) ARE NOT OVERWHELMING--SUB-SLAB SUCTION MIGHT OFFER POTENTIAL FOR SUSTAINED HIGH REDUCTIONS EVEN IN BASEMENT HOUSES WITH BLOCK FOUNDATION WALLS.

- SUB-SLAB SUCTION SOMETIMES MIGHT BE THE TECHNIQUE OF CHOICE IN BASEMENT HOUSES WITH POURED CONCRETE FOUNDATION WALLS, AND IN SLAB-ON-GRADE HOUSES.

- EFFORTS WILL CONTINUE TO UNDERSTAND AND OPTIMIZE THIS TECHNIQUE.

CURRENT RESULTS WITH DRAIN TILE SUCTION

House Number	Working Level		Approx. % Reduction
	Before	After (Winter)	
Drain Tiles Completely Surround House			
10	0.46-1.5	0-0.03	98
12	0.03-0.10	0.005-0.03	75
15	0.02-0.25	0.01-0.03	85
Drain Tiles Do Not Completely Surround House			
13	0.30-0.44	0.05-0.25	59
14	0.26-0.34	0.04-0.12	73
16	0.68-1.6	0.41-1.1	34
17	0.12-0.22	0.07-0.12	41

CONCLUSIONS ON DRAIN TILE SUCTION

- DRAIN TILE SUCTION APPEARS TO OFFER POTENTIAL WHEN THE DRAIN TILES COMPLETELY SURROUND THE HOUSE (EVEN WHEN INTERIOR BLOCK WALLS ARE PRESENT).

- DRAIN TILE SUCTION APPEARS VULNERABLE TO MILD SPIKES IN RADON CONCENTRATIONS WHEN BASEMENT IS DEPRESSURIZED (E.G., FIREPLACE OPERATED).

- DRAIN TILE SUCTION IS GENERALLY THE LEAST EXPENSIVE AND THE MOST AESTHETIC OF THE ACTIVE SOIL VENTILATION APPROACHES TESTED. IS COMPLETELY EXTERNAL TO THE HOUSE.